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**title:** ACOUSTIC SITING AND VERIFICATION OF THE  
HOLDING CAPACITY OF EMBEDMENT ANCHORS

**author:** R. J. Malloy and P. J. Valent

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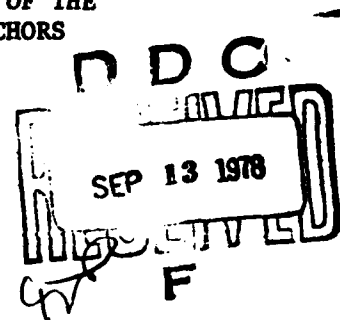


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The Finger Probe works like a bottom-finding pinger providing, in addition, data on sub-bottom reflectors. By monitoring the acoustic returns on the ship's precision depth recorder, the following data are provided in real time during the anchor implantment: (1) soil thickness over bedrock, (2) an indication of soil type, (3) sediment stratification and seafloor topography with better horizontal and vertical resolution than from surface-operated systems, and (4) a measure of anchor fluke embedment.

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## ABSTRACT

The most reliable method of determining the holding capacity of a direct embedment anchor is to perform a pullout test on a similar anchor in a soil profile identical as near as practicable to the soil profile at the site of the operational anchor. However, when available time and funding do not permit deployment of a test anchor, then some other way to verify the holding capacity of the operational anchor is required. To perform this anchor verification function, a 3.5 kHz battery-powered pinger system (Pinger Probe) has been developed, tested and evaluated. In some applications, use of the Pinger Probe can eliminate the necessity for a pre-installation site-survey, and can eliminate navigational errors resulting from attempts to reoccupy a favorable site (by providing the capability for simultaneous siting and installation).

Tests of the Pinger Probe were conducted at three oceanic sites, in conjunction with propellant-driven embedment anchor tests and in-situ soil property determinations using a seafloor-operating vane shear tower. At each anchor deployment a 3.5 kHz sound source (Pinger Probe) was attached on the anchor line a short distance above the anchor. The Pinger Probe works like a bottom-finding pinger providing, in addition, data on subbottom reflectors. By monitoring the acoustic returns on the ship's precision depth recorder, the following data are provided in real time during the anchor implantment:

- (1) soil thickness over bedrock,
- (2) an indication of soil type (i.e., sand, clay or bedrock),
- (3) sediment stratification and seafloor topography with better horizontal and vertical resolution than from surface-operated systems,
- (4) a measure of anchor fluke embedment.

## INTRODUCTION

### Objective

The objective of this work is to develop the technology base required to properly site direct embedment anchors, and to non-destructively verify the holding capacity of installed embedment anchors.

### Background

Direct embedment anchors are driven vertically into the seafloor sediments or into seafloor rocks, by an external driving force. The force may be derived from a launcher burning a propellant or from a vibratory or impulse pile-driver-type device. The fluke driven into the seafloor usually rotates or opens so as to present an enlarged bearing

area to the direction of pullout; this process of fluke change in orientation is called "keying." Environmental conditions exist where proper penetration and/or keying of the anchor flukes are impeded, resulting in reduced anchor holding capacities, e.g., proper penetration of the fluke can be impeded by rocks obscured by a thin cover of sediment (e.g., 1 - 5 m), or by fluke damage during deployment.

The chances of obtaining proper penetration of the anchor fluke can be improved by proper siting to make sure that no hard obstructions are encountered. Siting for these direct embedment anchors, especially the propellant-driven type, is usually based on a site survey conducted some days prior to the actual anchor deployment. Coring and core sample analyses, used in combination with shallow subbottom profiling, are usually recommended for the siting of embedment anchors. In addition, the combination of penetrometer drops and subbottom profiling is being developed to minimize the number of sediment cores that must be obtained and analyzed, possibly eliminating the need for core samples; a less costly, quicker survey technique.

Whichever site survey technique is used, the direct embedment anchor system must be appropriately positioned with respect to the corer and/or penetrometer locations and the subbottom profiler tracklines. Ordinarily, in the deep ocean, the variation of sediment properties over short distances is not very great, and the direct embedment anchor can be positioned with respect to the site survey locations with sufficient accuracy using existing positioning systems. However, near islands, seamounts, mid-ocean ridges and rises, trenches, and the continental shelves and slopes, often seafloor conditions change significantly over short distances. In these areas in particular, the requirement to install the embedment anchor within a small target area, so as to avoid the surrounding undesirable area, might exceed the capability of the positioning systems, especially when the siting survey and the anchor deployment are done at different times and use different positioning equipment.

Then, once the direct embedment anchor system has been positioned and triggered, the penetration depth of the anchor fluke should normally be measured and compared to the penetration predicted in order to indirectly verify the holding capacity of the anchor. If practical and justified economically, a proof load equal to the expected maximum static design load should be applied to the anchor downhaul line while simultaneously measuring the upward displacement of the fluke. During application of this proof load, the anchor fluke moves upward and rotates part of the way into its keyed position. Only when the soil depth of the fluke in this keyed or partially keyed position is known can a refined prediction of the ultimate holding capacity of that fluke be made and only then is the safety factor on the maximum working load known.

This report describes equipment and its use in solving the two above problems, namely, proper siting and proper evaluation of ultimate holding capacity. The equipment described is a 3.5 kHz, battery powered

pinger designed to be mounted on the lowering line for the anchor system a short distance above that system. The 3.5 kHz pinger (Pinger Probe) can assist in siting an anchor system by detecting thinly covered rock surfaces and by observing bottom and subbottom reflectors for correlation with previous site surveys; and the Pinger Probe serves double duty by also providing a measure of fluke penetration and displacement during keying.

The earliest published account of deployment of a 12 kHz bottom-finding pinger for subbottom penetration of the seafloor was by Ewing and others (1973). Two off-the-shelf pingers were used to help site corers in areas where the surface 3.5 kHz subbottom profiling data were discontinuous and in areas of complex topography. The term "Pinger Probe" was proposed for a pinger deployed for purposes of subbottom mapping.

In a more recent paper, Dow (1976) describes a similar use of a 12 kHz sound source designed specifically for near-bottom subbottom mapping. The device was capable of being triggered by the ship's recorder via a  $\frac{1}{4}$ " (6 mm) diameter single conductor logging cable, thereby eliminating data drift on the recorder. Additionally, the electric conductor could be used to conduct output and return signals for display on the ship's recorder. Dow proposed the name, "Acoustic Probe," for this application of acoustics. With the addition of the logging cable the "Acoustic Probe" becomes more versatile (such as in measuring Rayleigh reflection coefficient) but remains simple.

Of the two names suggested; Pinger Probe and Acoustic Probe; Pinger Probe seems more appropriate. It was suggested first in the literature, and the name is generic in that it describes an evolutionary consequence of the bottom-finding pinger. It also suggests a self-contained sound source of small size.

## EQUIPMENT

### Requirements

Valent (1976) listed four techniques that could be used to verify or check different factors impacting on or determining the holding capacity of a direct embedment anchor. The 3.5 kHz system impacts on three of the four verification techniques indicating a particularly high value for the development of this subseafloor sounding system. Also, in many instances the capability to detect subseafloor obstacles to the depth of maximum penetration expected, as is possible with the 3.5 kHz subseafloor sounding system, is indispensable. Hence a 3.5 kHz subbottom sounding system was proposed, developed, tested, and evaluated.

In order to meet the needs of the various verification techniques, the following required equipment characteristics were set down.

1. The 3.5 kHz pinger must meet the following minimum specifications:

- a. Water depth capability of 6,000 m,
- b. Signal level sufficient to produce interpretable reflections from rock surface beneath 10 m of sand cover and 15 m of clay cover, and have a
- c. Pinger operating life of 8 hours at 4°C.

2. The 3.5 kHz hydrophone should preferably be capable of being hung about 50 m beneath the ship to minimize interference due to hull and surface noise.

3. The data processing and display equipment should permit measurement of pinger distance above the seafloor to  $\pm 0.2$  m.

#### Equipment Used

The complete Pinger Probe system consists of a self-contained 3.5 kHz sound source with protective cage (Figure 1), plus a hydrophone and a recorder. The Ocean Research Equipment (O.R.E.) Model 265Z pinger consists of the O.R.E. Model 265A 12 kHz Bottom Finding Pinger, but with the 12 kHz transducer replaced with a larger, 3.5 kHz transducer: O.R.E. Model 138. The battery case and transducer are separate modules connected by a short length of electrical cable. The exact frequency is 3.42 kHz with a beam width of 60° defined by a 3 db drop in intensity. Pulse lengths of 0.5, 1.0, 2.0, and 10 milli-seconds are available. The minimum specified source level is 95 db referenced to 1  $\mu$  bar @ 1 yd. The pinger operates at any oceanic depth.

The battery package, timing circuitry, and power supply are housed in an aluminum case 4½ in. (0.115 m) in diameter and 34 in. (0.88 m) in length. Mass of this package is approximately 40 lbm (18 kg). The mass of the total unit is approximately 100 lbm (45 kg). Maximum external pressure rating is 1157 atmospheres. Since the power supply and transducer are connected by an electrical cable only, a steel cage was constructed to hold the two units together as well as to provide protection to the units. The steel cage also provided a means to carry the sonic probe and to store it in an upright position when not in use.

Power is supplied by 108 rechargeable 0.475 amp-hour nickel-cadmium cells, 150 volts when fully charged. An external plug facilitates battery charging without dismantling the power supply housing.

Other essential components in the system are a hydrophone to receive the bottom and subbottom acoustic returns and equipment to record the echo events, preferably a variable density recorder using paper with a wide dynamic range.

Except for preliminary testing in the Santa Barbara Channel, all of the Pinger Probe's deployments described here were from AGORs



equipped with hull-mounted 3.5 kHz transceivers and variable density, dry paper seismic recorders.

Since the recorder and Pinger Probe have separate timing bases, there is invariably a drift of the data on the recorder. This presents no problem because the drift is systematic, and the subbottom can be monitored regardless of drift.

The probe was typically positioned on the anchor cable 100 ft (30 m) above the anchor with a 3-ft (1 m) length of steel cable clamped to the anchor cable. A nylon safety line was also attached. The Pinger Probe was, therefore, allowed to swing freely about the vertical regardless of the scope of the anchor cable. This means that the probe was pointing directly at the anchor assembly only when the anchor cable was vertical.

When used in the installation of a direct embedment anchor in deep water, where ordinarily only one line, the mooring line, is used in the lowering process, then the Pinger Probe would be recovered by attaching buoyancy and allowing the Probe to slide/float back up along the mooring line or free-float to the surface. The buoyant Probe unit would most likely be freed from its attachment point on the mooring line by an acoustic-command release device. Recovery of a transponder by allowing it to slide/float up the mooring line has been demonstrated in the SEACON II cabled structure construction by Kretschmer and others (1976).

## TEST AND EVALUATION

The Pinger Probe system was deployed during three cruises: in the Santa Barbara Channel, in the Pacific Ocean 500 miles east of Hawaii, and at two sites in the Atlantic, one near the Bahamas and the other north of Puerto Rico.

### Santa Barbara Channel

The Pinger Probe was deployed at four sites in the Santa Barbara Channel where previous underway 3.5 kHz subbottom records had been made. The pinger was lowered by a nylon line at each site and placed on the bottom while recording the echo events. The Pinger Probe records resemble very closely the conventional surface deployed records in both penetration and resolution.

### East Pacific

The 3.5 kHz Pinger Probe was deployed eight times over an abyssal hills province in the NE Pacific 500 nm east of Hawaii with a water depth of 18,000 ft (5,500 m). On two 10K propellant-driven embedment anchor lowerings and two in-situ vane shear tower lowerings the pinger was placed on or near the seafloor. On five vane tower attempts, the

pinger was lowered to various depths as deep as 10,000 ft (3,050 m).

The pinger was set to ping twice per second. The penetration recorded from the pinger sound source was comparable to the ship's surface 3.5 kHz subbottom profiling system. Both penetration and resolution improved as the pinger approached bottom, as predicted. Maximum penetration recorded was around 150 ft (46 m). Based on the acoustic return the subbottom was determined to typically consist of 70 - 80 ft (21 - 24 m) of acoustically transparent probable pelagic clay, underlain by a layered sequence of echo events, possibly siliceous ooze.

The pinger was attached 100 ft (30 m) above the anchor and 500 ft (152 m) above the anchor on the two anchor deployments; and 500 ft (152 m) above the vane tower on its deployments. The echo from the anchor disappeared from the recording at a depth of 9,600 ft (2,926 m), whereas the vane tower reflection was visible on the recorder all the way to the bottom.

The 1 sec sweep also provided good resolution. This opens up the option of pinging twice a second but with alternating ping length or different frequency to optimize both penetration and resolution. Because the seafloor was so uncomplicated both topographically and lithologically the siting capabilities of the acoustic probe could not be fully demonstrated.

#### Western Atlantic

The Pinger Probe was deployed at two test sites in the Atlantic. The first site was north of Grand Bahama Island in 3,668 ft (1,118 m) of water, an area of coarse-grained calcareous ooze (Figure 2). The second site was north of Puerto Rico in 17,500 ft (5,334 m) of water, an area of pelagic clay.

Eight CEL 10K propellant-driven direct embedment anchors were deployed for test purposes. The 3.5 kHz Pinger Probe was attached in each deployment 100 ft (30 m) above the anchor assembly. Figure 2 shows a fathogram record at one of the anchor installations at Site I. Note the better resolution of subbottom layering from the hull-mounted pinger record. Although the anchor assembly (anchor and gun assembly) (Figure 2) returned recognizable echos while being lowered and the gun assembly (Figure 3) was detected while being raised, the gun assembly was not recorded while the anchor fluke was embedded. This may have been caused by the ship drifting off-station pulling the Pinger Probe too far off to one side of the gun assembly for it to be ensonified by the vertically oriented main beam of the 3.5 kHz transducer. Upon pulling the anchor free of the bottom the lower portion of the line swung to the vertical close enough to the axis of the ensonified cone for the gun assembly and the fluke to be detected. The subbottom data show at least 50 ft (15 m) of sediment at the point of anchor impact.

## DISCUSSION

The tests of the Pinger Probe demonstrated the effectiveness and convenience of using that seafloor penetrating pinger for the siting of direct embedment anchor systems and for measuring the depth of embedment of the unkeyed and keyed anchor flukes. For the tests conducted, the slight drift in the data record, resulting from the completely independent timing systems of the shipboard recorder and the battery operated pinger, did not cause any undue difficulty. However, for some systems this data drift might become erratic, justifying an interconnected recorder pinger system. Dow (1976) described such an interconnected system.

Dow's "acoustic probe" was designed to provide near-bottom subbottom data. The 12 kHz sound source carries its own power supply and battery pack, but is triggered by a recorder aboard ship via a  $\frac{1}{4}$  in. (6 mm) diameter single conductor logging cable, which also was used to conduct the transduced echo events back to the recorder for display. This technique adds the complication of an electric conductor, but, since the sound source is synchronized by the recorder, the bottom and subbottom data do not drift on the recorder. A larger advantage is gained by Dow's near-bottom receiver which prevents surface noise being added to the recording. Yet another advantage mentioned by Dow is the ability to tape record the data, apply software manipulations, and display on a paper recorder. A sharply defined trigger event makes this possible. These considerations suggest that the 3.5 kHz Pinger Probe could be manufactured with the necessary plug-in circuitry to make the trigger and data return capability an option.

## CONCLUSIONS

1. The depth of acoustic return (large compared to anchor penetration) fulfilled the design criteria.
2. Resolution improved over surface deployed 3.5 kHz subbottom profiling as water depth increased.
3. The 3.5 kHz Pinger Probe system operation did not interfere with the anchor installation procedures.
4. The gun assembly could not be detected after anchor embedment. This was caused by the Pinger Probe directing its sound vertically downward, instead of down the anchor cable.

## RECOMMENDATION

1. More experience using the 3.5 kHz Pinger Probe system should

be obtained so that its verification potential can be accurately assessed.

2. The Pinger Probe performance should be tested when attached to the anchor cable with its long axis parallel to the anchor cable.

3. There should be some way of knowing when the anchor cable is vertical, or nearly so. This might be accomplished by having the Pinger Probe signal when the anchor cable is within  $10^0$  of vertical, for instance. This is important to know when proof testing, setting flukes, or in pulling out the anchor.

4. The anchor siting/verification probe should be capable of functioning as a transceiver, returning the echo events by hard wire to the ship's recorder and using the same wire for triggering the sound source by the ship's recorder. This inexpensive option would provide:

- a. perfect synchronization with the ship's recorder, thereby preventing drift,
- b. capability to ping rapidly providing better resolution,
- c. capability to avoid acoustic noise levels which increase with decreasing depth,
- d. capability to monitor reflection amplitudes more accurately for quantitative acoustic measurements,
- e. capability to turn the probe off while at depth.

5. The possibility of reducing the weight, size, and cost of the probe assembly should be investigated.

6. An improvement may result by designing the Pinger Probe to alternate frequencies, 12 and 3.5 kHz, for instance, to optimize resolution and penetration.

#### ACKNOWLEDGMENTS

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Figure 1. Pinger Probe with protective steel cage. The 3.5 kHz transducer is at the lower end, and the battery, power supply, and timing circuitry are housed in the cylindrical module above.



Figure 2. Acoustic (3.5 kHz) record of anchor deployment on 11 Sep 1977 at  $28^{\circ} 0.1' N$ ,  $77^{\circ} 11.1' W$ , recorded aboard USNS LYNCH on 19" dry facsimile paper. The slope of the traces representing the direct and reflected signals from the Pinger Probe during the time of anchor embedment results from a drift in the time base of the Pinger Probe relative to the time base of the recorder.

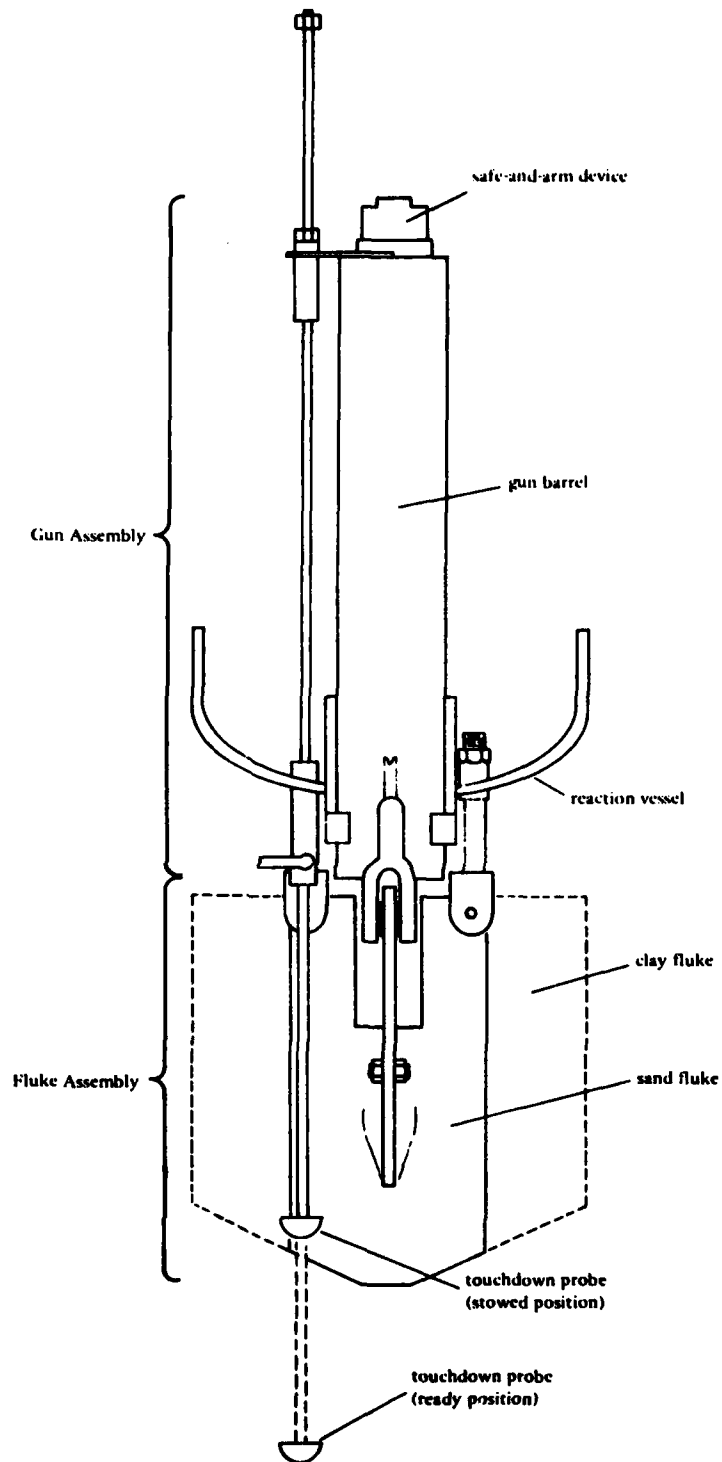


Figure 3. Schematic of the CEL 10K propellant-actuated anchor. Reaction vessel has 24" (0.61 m) diameter. After Wadsworth and Taylor (1976).



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 NAVOCEANSYSCEN Code 2010 San Diego, CA; Code 409 (D. G. Moore), San Diego CA; Code 4473 Bayside Library, San Diego, CA; Code 52 (H. Talkington) San Diego CA; Code 5204 (J. Stachiw), San Diego, CA; Code 5214 (H. Wheeler), San Diego CA; Code 5224 (R. Jones) San Diego CA; Code 5311(T) (E. Hamilton) San Diego CA; Code 6565 (Tech. Lib.), San Diego CA; Code 7511 (PWO) San Diego, CA  
 NAVPGSCOL D. Leipper, Monterey CA; E. Thornton, Monterey CA; J. Garrison Monterey CA  
 NAVPHIBASE CO, ACB 2 Norfolk, VA; Code S3T, Norfolk VA; Harbor Clearance Unit Two, Little Creek, VA; OIC, UCT ONE Norfolk, Va  
 NAVREGMEDCEN SCE (D. Kaye); SCE, Guam  
 NAVSEASYSYSCOM Code OOC (LT R. MacDougal), Washington DC; Code SEA OOC Washington, DC  
 NAVSEC Code 6034 (Library), Washington DC  
 NAVSHIPREFPAC Library, Guam; SCE Subic Bay  
 NAVSHIPYD; Code 202.4, Long Beach CA; Code 440 Portsmouth NH; Code 440, Puget Sound, Bremerton WA; Code 440.4, Charleston SC; Salvage Supt, Phila., PA; Tech Library, Vallejo, CA  
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 NAVSTA BISHOPS POINT Harbor Clear. Unit one, Pearl Harbor, HI  
 NAVSUBASE LTJG D.W. Peck, Groton, CT  
 NAVSUPPACT Code 413, Seattle WA; LTJG McGarrah, Vallejo CA; Security Offr, San Francisco, CA  
 NAVSURFWPCEN PWO, White Oak, Silver Spring, MD  
 NAVTECHTRACEN SCE, Pensacola FL  
 NAVWPNCEN Code 2636 (W. Bonner), China Lake CA  
 NAVWPNSTA EARLE Code 092, Colts Neck NJ; PW Office (Code 09C1) Yorktown, VA; PWO, Seal Beach CA  
 NAVWPNSUPPCEN Code 09 (Boennighausen) Crane IN  
 NAVXDIVINGU LT A.M. Parisi, Panama City FL  
 NCBU 405 OIC, San Diego, CA  
 NCBC CEL (CAPT N. W. Petersen), Port Hueneme, CA; CEL AOIC Port Hueneme CA; Code 10 Davisville, RI; Code 155, Port Hueneme CA; Code 156, Port Hueneme, CA  
 NOAA Librarym Rockville, MD  
 NORDA Code 410 Bay St. Louis, MS; Code 440 (Ocean Rsch Off) Bay St. Louis MS  
 NRL Code 8400 (J. Walsh), Washington DC; Code 8441 (R.A. Skop), Washington DC; Rosenthal, Code 8440, Wash. DC  
 NSD SCE, Subic Bay, R.P.  
 NTC Code 54 (ENS P. G. Jackel), Orlando FL  
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 NUSC Code 131 New London, CT; Code EA123 (R.S. Munn), New London CT; Code S332, B-80 (J. Wilcox); Code TA131 (G. De la Cruz), New London CT  
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 PMTC Code 3331 (S. Opatowsky) Point Mugu, CA; EOD Mobile Unit, Point Mugu, CA; Pat. Counsel, Point Mugu CA  
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 USCG (G-ECV) Washington Dc; (G-ECV/61) (Burkhart) Washington, DC; (G-MP-3/USP/82) Washington Dc;  
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